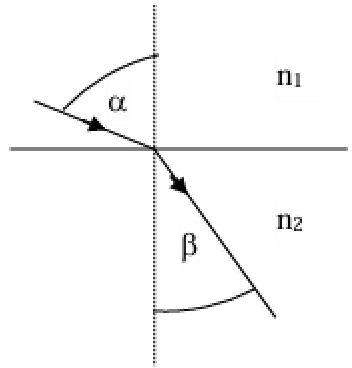
D2. Examining the Dependence of the Refractive Index on the Solution Concentration Using Abbe Refractometer

***The aim of the exercise** is to observe the optical phenomena that occur at the boundary between two transparent media and to experimentally determine the refractive index using the method of total internal reflection.*

The Law of Refraction (Snell's Law)

The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for two given media and equals the ratio of their absolute refractive indices n_2/n_1, or the relative refractive index of the second medium with respect to the first. This is also equal to the ratio of the speed of light in the first medium v_1, to the speed in the second v_2:



$$\frac{sin\alpha}{sin\beta} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{2,1}. \qquad (1)$$

The incident ray, the normal at the point of incidence, and the refracted ray all lie in the same plane.

The **absolute refractive index *n*** is defined as the ratio of the speed of light in vacuum *c* to the speed of light in a given medium *v*:

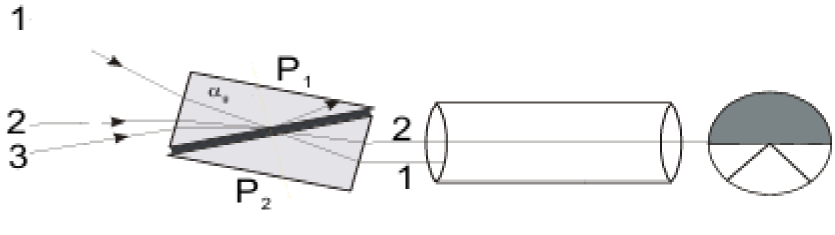
$$n = \frac{c}{v}. \qquad (2)$$

The critical angle α_b is defined as the angle of incidence for which the refractive angle equals 90°. This can occur only when the light travels from the optically denser medium to the less dense one. For that case, using the equation (1) and the reversibility principle of light, the following can be derived:

$$n_{2,1} = \frac{sin90°}{sin\alpha_b} = \frac{1}{sin\alpha_b}. \qquad (3)$$

For angles of incidence greater than the critical angle, **total internal reflection** occurs, meaning the entire light beam is reflected within the denser medium. This principle is used in **refractometers** to determine refractive indices experimentally by measuring the critical angle (based on equation 3).

The Abbe refractometer principle is presented below:



The Abbe refractometer consists of two prisms with a higher refractive index than the tested liquid placed between them (prisms P_1 and P_2). The sample forms a thin, flat-parallel layer between the prisms. Rays exiting prism P_1 strike this layer at various angles. Some rays are totally internally reflected while others are transmitted and leave prism P_2.

Rays at the critical angle travel along the boundary surface and are absorbed by the blackened inner walls of the prism housing. As a result, the field of view through the eyepiece is divided into bright and dark areas. By adjusting a knob, the boundary line between these areas is aligned with the crosshair, and the **refractive index** of the tested liquid or solution is read directly from the scale.

D2. Measurement and calculation protocol

Pair No.:	Student's name and surname:	Field of study: Group:
Date:	Teacher's name and surname:	Passing information:

Measuring protocol:

Equipment: Abbe refractometer (with built-in sodium lamp), set of solutions of various concentrations.

Measuring steps:

1. Plug in the sodium lamp mounted inside the upper prism (2) of the refractometer (see Fig. 1).
2. Open the upper prism, rinse both prisms with distilled water, and gently wipe with a paper towel.
3. Apply a thin layer of water onto the lower prism to fully cover its surface. Close and lock the upper prism using the **LOCK** knob on the left, and remove any excess water with a paper towel.
4. Adjust the eyepiece to clearly see the crosshair and scale. The scale is dual (see Fig. 2):
   - **Lower part**: Refractive index values (used in this experiment)
   - **Upper part**: Sucrose solution concentrations (not used here)
5. In the eyepiece field of view, the image should be split into light and dark fields. Use the DISPERSION CORRECTION knob (3) on the right side to correct any color fringing.
6. Rotate the ADJUSTMENT knob (4) to move the boundary line between the light and dark fields to the center of the crosshair (see Fig. 2).
7. Read the refractive index from the lower scale in the eyepiece field.
8. Clean the prism surfaces and apply the first (lowest concentration) solution. Measure the refractive index as done with water.
9. Repeat for all other known concentrations and for the solution with unknown concentration c_x.

Fig. 1. The Abbe Refractometer: 1-eyepiece with scale; 2-upper illuminating prism; 3-dispersion correction knob; 4-setting knob; 5-thermometer

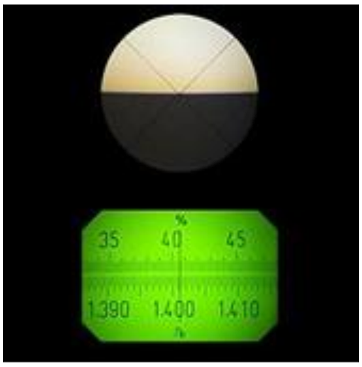


Fig. 2. The field of view in the eyepiece of the Abbe Refractometer

Data table

c [%]	0 (water)						c_x
n	n_0=						n_x=

$\Delta n=\Delta n_0=\Delta n_x$ = ……………………

Data analysis and calculations:

1. Plot the graph n=f(c) (using the plotting paper)
2. Determine the slope of the line (directional coefficient), which equals the refractive index increment *d* – the rate of change of refractive index with increasing concentration. Also, determine the absolute error *Δd*. The appropriate software can be used for those purposes. Present rounded values of *d* and *Δd*:

$$d = (\dots\dots\dots\dots\dots\dots.. \pm \cdots \dots\dots\dots\dots\dots.)\ [\dots\dots..]$$

3. Use the slope value to calculate the unknown concentration c_x of the solution:

$$c_x = \frac{n_x - n_0}{d}$$

   Where n_x is the refractive index of the solution of unknown concentration and n_0 is the refractive index of the solvent (water).

4. Calculate the error of c_x using the total differential method:

$$\Delta c_x = \left|\frac{1}{d}\right| \Delta n_x + \left|\frac{-1}{d}\right| \Delta n_0 + \left|\frac{n_x - n_0}{d^2}\right| \Delta d$$

   where $\Delta n_x = \Delta n_0$ are the readings error of the refractive index and *Δd* is the calculated uncertainty of the slope (i.e. refractive index increment)

5. Present the final rounded values of the unknown concentration, accompanied by its uncertainty. The results should be expressed in SI units:

$$c_x \pm \Delta c_x = (\dots\dots\dots\dots\dots \pm \cdots \dots\dots\dots\dots)\ [\dots\dots]$$